Manifestaion of SUSY in B decays [a]

YASUHIRO OKADA
Institute for Particle and Nuclear Studies, KEK,
Oho 1-1, Tsukuba 305-0801, Japan
E-mail: yasuhiro.okada@kek.jp

SUSY effects on various flavor changing neutral current processes are discussed in the minimal supergravity model and the SU(5) grand unified theory with right-handed neutrino supermultiplets. In particular, in the latter case the neutrino Yukawa coupling constants can be a source of the flavor mixing in the right-handed-down-type-squark sector. It is shown that due to this mixing the time-dependent CP asymmetry of radiative B decay can be as large as 30% and the ratio of B_s–$\bar{B}_s$ mixing and B_d–$\bar{B}_d$ mixing deviates from the prediction in the standard model and the minimal supergravity model without the neutrino interaction.

1 Introduction

In order to explore supersymetry (SUSY) indirect search experiments can play a complementary role to direct search for SUSY particles at collider experiments. Since SUSY particles may affect flavor changing neutral current (FCNC) processes and CP violation in B and K meson decays, it is possible that new experiments in B decay at both e^+e^- colliders and hadron machines reveal new physics signals which can be interpreted as indirect evidence of SUSY.

In the context of SUSY models flavor physics has important implications. Because the squark and the slepton mass matrices become new sources of flavor mixings generic mass matrices would induce too large FCNC and lepton flavor violation (LFV) effects if the superpartners' masses are in a few-hundred-GeV region. For example, if we assume that the SUSY contribution to the $K^0 - \bar{K}^0$ mixing is suppressed because of the cancellation among the squark contributions of different generations, the squarks with the same gauge quantum numbers must be highly degenerate in masses at least for the first two generations.

There are several scenarios to solve this flavor problem. In the minimal supergravity model flavor problem are avoided by taking SUSY soft-breaking terms as flavor-blind structure. The scalar mass terms are assumed to be common for all scalar fields at the Planck scale and therefore there are no FCNC effects nor LFV from the squark and slepton sectors at this scale. The physical

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squark and slepton masses are determined taking account of renormalization effects from the Planck to the weak scale. This induces sizable SUSY contributions to various FCNC and LFV processes.

In this talk we consider two types of SUSY models and discuss FCNC processes. The first one is the minimal supersymmetric standard model (MSSM) with a universal SUSY breaking terms at the Planck scale which is realized in the minimal supergravity model. The other is the SU(5) grand unified theory with right-handed neutrino supermultiplets. This model incorporates the seesaw mechanism for neutrino mass generation. In the latter case the neutrino Yukawa coupling constants can be a source of the flavor mixing in the right-handed-down-type-squark sector and due to this mixing the time-dependent CP asymmetry of radiative B decay can be as large as 30% and the ratio of B_s–$\bar{B}_s$ mixing and B_d–$\bar{B}_d$ mixing deviates from the prediction for the standard model (SM) and the MSSM without the neutrino interaction.

2 Update of FCNC Processes in the Supergravity Model

In the minimal SM various FCNC processes and CP violation in B and K decays are determined by the Cabibbo-Kobayashi-Maskawa (CKM) matrix. Constraints on the parameters of the CKM matrix can be conveniently expressed in terms of the unitarity triangle. With CP violation at B factory as well as rare K decay experiments we will be able to check consistency of the unitarity triangle and at the same time search for effects of physics beyond the SM. In order to distinguish possible new physics effects it is important to identify how various models can modify the SM predictions.

Although general SUSY models can change the lengths and the angles of the unitarity triangle in variety ways, the supergravity model predicts a specific pattern of the deviation from the SM.[1] Namely, we can show that the SUSY loop contributions to FCNC amplitudes approximately have the same dependence on the CKM elements as the SM contributions. In particular, if we assume that there are no CP violating phases from SUSY breaking sectors, the complex phase of the $B^0 - \bar{B}^0$ mixing amplitude does not change even if we take into account the SUSY contributions. The case with supersymmetric CP phases was also studied within the minimal supergravity model and it was shown that effects of new CP phases on the $B^0 - \bar{B}^0$ mixing amplitude and the direct CP asymmetry in the $b \to s\,\gamma$ process are small once constraints from neutron and electron EDMs are included.[2]

We calculate various FCNC processes in the supergravity model with universal soft breaking terms at a high energy scale. The results are summarized as follows.

1. The amplitude for $b \to s\gamma$ can receive a large contribution from the SUSY and the charged-Higgs-top-quark loop diagrams. The experimental branching ratio puts a strong constraint on SUSY parameter space. Since the SUSY contribution can interfere with other contributions either constructively or destructively we cannot exclude the light charged Higgs boson region unlike the non-SUSY type II two Higgs doublet model.[3]

2. When the sign of the $b \to s\gamma$ amplitude is opposite to that of the SM, $\mathrm{B}(b \to sl^+l^-)$ can be twice larger than the SM prediction. This can occur for a large $\tan\beta$ region where $\tan\beta$ is the ratio of two vacuum expectation values of Higgs fields. The deviation is also evident in the differential branching ratio and the lepton forward-backward asymmetry.[4]

3. In terms of consistency check of the unitarity triangle the supergravity model has the following features.[5] (i)ΔM_{B_d} and ϵ_K are enhanced by the SUSY and charged-Higgs loop effects. When these quantities are normalized by the corresponding quantities in the SM they are almost independent of the CKM matrix element, and the enhancement factors for ΔM_{B_d} and ϵ_K are almost equal. (ii) The branching ratios for $K^+ \to \pi^+ \nu \overline{\nu}$ and $K_L \to \pi^0 \nu \overline{\nu}$ processes are suppressed compared to the SM prediction. Again the suppression factor are almost the same for two branching ratios and does not depend strongly on the CKM matrix element. (iii) CP asymmetries in various B decay modes such as $B \to J/\psi K_S$ and the ratio of ΔM_{B_s} and ΔM_{B_d} are the same as the SM prediction.

In Fig. 1 we present the correlation between ΔM_{B_d} and $\mathrm{B}(K_L \to \pi^0 \nu \overline{\nu})$ normalized by the corresponding quantities in the SM for $\tan\beta = 3$. The constraint on the SUSY parameter space from the recent improved SUSY Higgs search is implemented.[5] We have calculated the SUSY particle spectrum based on two different assumptions on the initial conditions of renormalization group equations. The minimal case corresponds to the minimal supergravity where all scalar fields have a common SUSY breaking mass at the GUT scale. For "nonminimal" we enlarge the SUSY parameter space by relaxing the initial conditions for the SUSY breaking parameters, namely all squarks and sleptons have a common SUSY breaking mass whereas an independent SUSY breaking parameter is assigned for Higgs fields. The square(dot) points correspond to the minimal (enlarged) parameter space of the supergravity model. We can see that the ΔM_{B_d} (and ϵ_K) can deviated from the SM by 20% whereas the deviation in $K_L \to \pi^0 \nu \overline{\nu}$ and $K^+ \to \pi^+ \nu \overline{\nu}$ processes are small. These deviations may be evident in future when B factory experiments provide additional information on the CKM parameters.

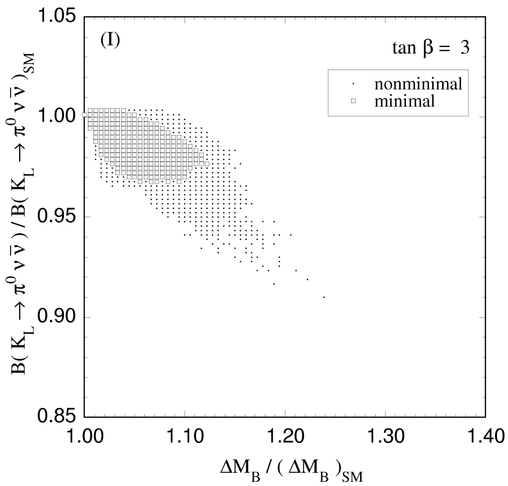

Figure 1: Correlation between ΔM_{B_d} and ϵ_K normalized by the SM value for $\tan\beta = 3$. The square(dot) points correspond to the minimal (enlarged) parameter space of the supergravity model.

3 FCNC in SUSY GUT with Right-handed Neutrino

In this section we consider FCNC and LFV of charged lepton decays in the model of a SU(5) SUSY GUT which incorporates the see-saw mechanism for the neutrino mass generation.[6] In this model sources of the flavor mixing are Yukawa coupling constant matrices for quarks and leptons as well as that for the right-handed neutrinos. Because the quark and lepton sectors are related by GUT interactions, the flavor mixing relevant to the CKM matrix can generate LFV such as $\mu \to e\,\gamma$ and $\tau \to \mu\,\gamma$ processes [7] in addition to FCNC in hadronic observables.[8] In the SUSY model with right-handed neutrinos, branching ratios of the LFV processes can become large enough to be measured in near-future experiments. [9] When we consider the right-handed neutrinos in the context of GUT, the flavor mixing related to the neutrino oscillation can be a source of the flavor mixing in the squark sector. We show that due to the large mixing of the second and third generations suggested by the atmospheric neutrino anomaly, B_s–$\bar{B}_s$mixing, the time-dependent CP asymmetry of the $B \to M_s\,\gamma$ process, where M_s is a CP eigenstate including the strange quark, can have a large deviation from the SM prediction.[6]

The Yukawa coupling part and the Majorana mass term of the superpotential for the SU(5) SUSY GUT with right-handed neutrino supermultiplets is

given by $W = \frac{1}{8} f_U^{ij} \Psi_i \Psi_j H_5 + f_D^{ij} \Psi_i \Phi_j H_{\bar{5}} + f_N^{ij} N_i \Phi_j H_5 + \frac{1}{2} M_\nu^{ij} N_i N_j$,where Ψ_i, Φ_i and N_i are $\mathbf{10}$, $\bar{\mathbf{5}}$ and $\mathbf{1}$ representations of SU(5) gauge group. $i, j = 1, 2, 3$ are the generation indices. H_5 and $H_{\bar{5}}$ are Higgs superfields with $\mathbf{5}$ and $\bar{\mathbf{5}}$ representations.

The renormalization effects due to the Yukawa coupling constants induce various FCNC and LFV effects from the mismatch between the quark/lepton and squark/slepton diagonalization matrices. In particular the large top Yukawa coupling constant is responsible for the renormalization of the $\tilde{q}_L$ and $\tilde{u}_R$ mass matrices. At the same time the $\tilde{e}_R$ mass matrix receives sizable corrections between the Planck and the GUT scales and various LFV processes are induced. In a similar way, if the neutrino Yukawa coupling constant f_N^{ij} is large enough, the $\tilde{l}_L$ mass matrix and the $\tilde{d}_R$ mass matrix receive sizable flavor changing effects due to renormalization between the Planck and the right-handed neutrino mass scales and the Planck and the GUT scales, respectively. These are sources of extra contributions to LFV processes and various FCNC processes such as $b \to s\,\gamma$, the B^0–$\overline{B}^0$ mixing and the K^0–$\overline{K}^0$ mixing.

The flavor mixing in the $\tilde{d}_R$ sector can induce large time-dependent CP asymmetry in the $B \to M_s\,\gamma$ process. Using the Wilson coefficients c_7 and c_7' in the effective Lagrangian for the $b \to s\,\gamma$ decay $\mathcal{L} = c_7 \bar{s} \sigma^{\mu\nu} b_R F_{\mu\nu} + c_7' \bar{s} \sigma^{\mu\nu} b_L F_{\mu\nu} + H.c.$, the asymmetry is written as $\frac{\Gamma(t) - \bar{\Gamma}(t)}{\Gamma(t) + \bar{\Gamma}(t)} = \xi A_t \sin \Delta m_d t, \quad A_t = \frac{2\mathrm{Im}(\mathrm{e}^{-\mathrm{i}\theta_\mathrm{B}} \mathrm{c}_7 \mathrm{c}_7')}{|c_7|^2 + |c_7'|^2}$, where $\Gamma(t)$ ($\bar{\Gamma}(t)$) is the decay width of $B^0(t) \to M_s\,\gamma$ ($\bar{B}^0(t) \to M_s\,\gamma$) and M_s is some CP eigenstate ($\xi = +1(-1)$ for a CP even (odd) state) such as $K_S\,\pi^0$.[10] $\Delta m_d = 2|M_{12}(B_d)|$ and $\theta_B = \arg M_{12}(B_d)$ where $M_{12}(B_d)$ is the B_d–$\bar{B}_d$ mixing amplitude. Because the asymmetry can be only a few percent in the SM, a sizable asymmetry is a clear signal of new physics beyond the SM.

We calculated various FCNC and LFV observables in this model under the assumption of the universal soft breaking terms at the Planck scale. As typical examples of the neutrino parameters, we consider the following parameter set corresponding to the Mikheyev-Smirnov-Wolfenstein (MSW) small mixing case. $m_\nu = \left(2.236 \times 10^{-3},\, 3.16 \times 10^{-3},\, 5.92 \times 10^{-2}\right)$ eV and the Maki-Nakagawa-Sakata (MNS) matrix is given by

$$V_{\mathrm{MNS}} = \begin{pmatrix} 0.999 & 0.0371 & 0 \\ -0.0262 & 0.707 & 0.707 \\ 0.0262 & -0.707 & 0.707 \end{pmatrix} .$$

We also take M_ν to be proportional to a unit matrix with a diagonal element of $M_R = 4 \times 10^{14}$ GeV. We fix CKM parameters as $V_{cb} = 0.04$, $|V_{ub}/V_{cb}| = 0.08$ and $\delta_{13} = 60^\circ$. We take $\tan\beta = 5$ and vary other SUSY parameters. We take

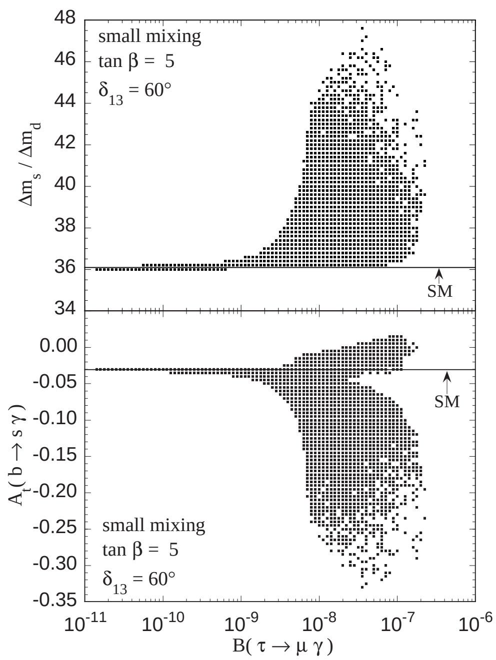

Figure 2: The ratio of B_s–$\bar{B}_s$ and B_d–$\bar{B}_d$ mass splittings $\Delta m_s/\Delta m_d$ and the magnitude factor A_t of the time-dependent CP asymmetry in the $B \to M_s\,\gamma$ process as a function of $\mathrm{B}(\tau \to \mu\,\gamma)$ for the small mixing.

account of various phenomenological constraints on SUSY parameters including $\mathrm{B}(b \to s\,\gamma)$. We also calculated $\mathrm{B}(\mu \to e\,\gamma)$ and ϵ_K and imposed constraints from these quantities. The upper part of Fig.2 shows a correlation between $\Delta m_s/\Delta m_d$ (ratio of B_s–$\bar{B}_s$ and B_d–$\bar{B}_d$ mass splittings) and $\mathrm{B}(\tau \to \mu\,\gamma)$. We can see that $\Delta m_s/\Delta m_d$ can be enhanced up to 30% compared to the SM prediction. This feature is quite different from the minimal supergravity model without the GUT and right-handed neutrino interactions[5] where $\Delta m_s/\Delta m_d$ is almost the same as the SM value. A_t for the same parameter set is shown as a function of $\mathrm{B}(\tau \to \mu\,\gamma)$ in the lower part of Fig. 2. We can see that $|A_t|$ can be close to 30% when $\mathrm{B}(\tau \to \mu\,\gamma)$is larger than 10^{-8}. The large asymmetry arises because the renormalization effect due to f_N induces sizable contribution to c_7' through gluino–$\tilde{d}_R$ loop diagrams. In this example possible new physics signals in $\mathrm{B}(\tau \to \mu\,\gamma)$, B_s–$\bar{B}_s$ mixing and A_t all come from the renormalization effect on squark and slepton mass matrices from the large neutrino Yukawa coupling

constant. Because these signals provide quite different signatures compared to the SM and the minimal supergravity model without GUT and right-handed neutrino interactions, future experiments in B physics and LFV can provide us important clues on the interactions at very high energy scale.

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